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Wood Plastic Composites - A Primer -

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Introduction

Wood plastic composite is a relatively new material that has many potential uses. The markets for WPC decking lumber have been expanding recently and new applications are being pursued.

Door and window components, deck handrails and fencing are other markets for the WPC industry. The flexibility of manufacturing methods and product performance attributes provide the potential for a variety of new markets.

This publication is intended as an introduction to wood plastic composite technology for those people who are interested in WPC technology and their applications.

What are WPCs?

Wood plastic composites (WPCs) are roughly 50:50 mixtures of thermoplastic polymers and small wood particles. The wood and thermoplastics are usually compounded above the melting temperature of the thermoplastic polymers and then further processed to make various WPC products. WPC can be manufactured in a variety of colors, shapes and sizes, and with different surface textures. Depending on the processing method, WPCs can be formed into almost any shape and thus are used for a wide variety of applications, including windows, door frames, interior panels in cars, railings, fences, landscaping timbers, cladding and siding, park benches, molding and furniture. One commonly available example of WPCs is the decking lumber that is often better known by its various brand names – e.g., Trex™, ChoiceDek™, Eon™ or SmartDeck™ – or as the generic term “composite lumber.”

Advantages

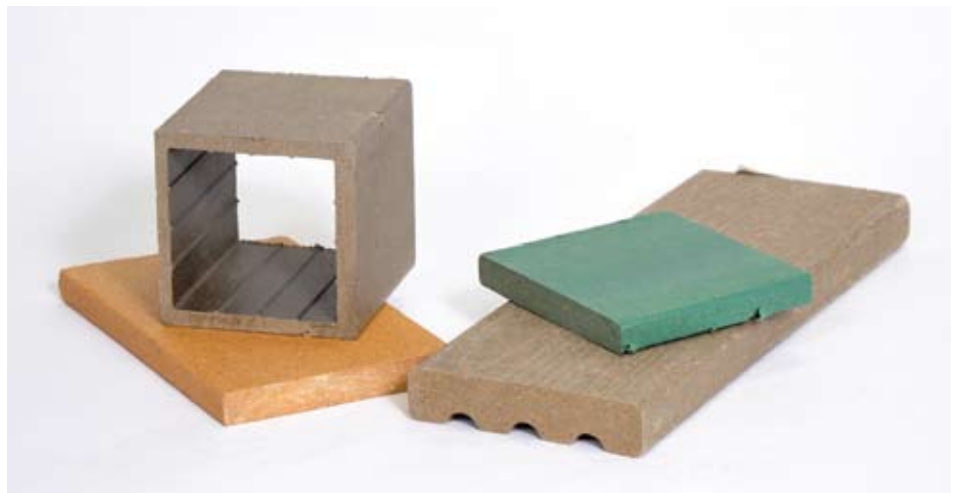
WPCs offer a number of potential benefits. The presence of wood in a plastic matrix can result in a stiffer and lower-cost material than if plastic alone was used. Also, the compression properties (resistance to crushing) for most WPCs are superior to that of wood loaded perpendicular to the grain. The plastic in the product is not subject to water absorption or biological attack, so the WPC can have lower maintenance requirements than solid wood. WPC lumber will not warp, splinter or check.

The use of wood – a natural and renewable resource – can reduce the “carbon footprint” of plastics, because less fossil energy and material are required to make the final product. WPCs are also potentially recyclable, because recovered material can be melted and re-formed. WPCs may be identified as sustainable materials, due to the wood particles predominately being a byproduct of sawmill and other wood-processing waste streams, and because much of the plastic is derived from consumer and industrial recycling efforts.

WPCs offer great flexibility in the shapes and colors of the materials produced. Materials usage can be also be reduced through the engineering of special shapes – e.g., hollow-core decking boards.

Disadvantages

The wood component within WPCs does impart some positive attributes compared to plastic; however, the inherent problems with wood (moisture sorption and susceptibility to mold and decay) remain. Water can penetrate into



WPCs can be produced in almost any color and shape. Hollow decking boards can reduce material usage.

WPCs, albeit at a much lower rate and level compared to solid wood or other wood composites. The resulting sorption of water can promote the growth of mold and decay fungi; however, aesthetics – not structural issues – dominate consumer callbacks. Color fade from sunlight is also accelerated when wood is added to thermoplastics, causing a whitening or graying of the surface of the composite.

WPCs are also usually quite heavy and not as stiff as solid wood. This limits the potential use of WPCs in many structural applications and creates the potential creep or sagging problems, especially in a warm environment. On the other hand, this flexibility can be an advantage: WPC can be bent on-site to make attractive patterns.

WPC is touted as having environmental benefits, because it is made from residues (wood) or recycled materials (plastic). However, virgin plastics are commonly supplemented in WPC operations to maintain tighter quality control and offset highly fluctuating recycled plastic inventories. WPC also requires large amounts of energy to produce. WPC is theoretically recyclable; it could be re-melted and re-formed into new decking lumber. However, no recycling of this new product is currently underway, with exception of recycling of off-specification material during manufacture. The collection, cleaning and transportation of old WPC to a recycling center for remanufacture are likely to be prohibitively expensive.

Codes and standards

ASTM standards to assess performance of WPCs relative to building code requirements have been developed. These include:

- **ASTM D 7031-04** Guide for Evaluating Mechanical and Physical Properties of Wood-plastic Composite Products
- **ASTM D 7032-04** Specification for Establishing Performance Ratings for Wood-plastic Composite Deck Boards and Guardrail Systems Guards or Handrails
- **ASTM D 6662-01** Specification for Polyolefin-based Plastic Lumber Decking Boards

Other standards exist that pertain to specific applications. These would apply to WPC products, if they were used in those applications. Some examples include:

- **Roofing Material**
[IBC standards for roofing-related materials](#)
- **Playground Equipment**
[F1487-01e1](#) Standard Consumer Safety Performance Specification for Playground Equipment for Public Use
- **F1148-03** Standard Consumer Safety Performance Specification for Home Playground Equipment
- **Products used in buildings in wildfire risk areas:**
[12-7A-2](#) Fire-Resistive Standards for Exterior Windows
[12-7A-1](#) Fire-Resistive Standards for Exterior Wall Siding and Sheathing

- [12-7A-5](#) Fire-Resistive Standards for Decks and Other Horizontal Ancillary Structures

How WPCs are made

WPCs are commercially produced by a number of companies throughout the world. While there is considerable variation in the process employed and the products produced, there are many common elements. This section will briefly describe the components of WPCs and how they are put together.



WPCs are manufactured in facilities across the United States. For more information, visit <http://www.wpcinfo.org/>

Wood

Particle geometry

Wood used in WPC manufacturing is in the form of dry particles with a powdery consistency, often called “wood flour.” In general, the wood waste ‘raw material’ is in the form of sawdust and/or planer shavings.

There are two steps to produce wood flours: size reduction and size classification (screening). In case of large pieces of wood, size may be reduced using equipment such as a hammer mill, hog or chipper. Wood



Any species can be incorporated into WPCs. Non-wood fibers can also be used.

from such processes is coarse and is usually ground further using an attrition mill (grinding between disks), rollers, hammer or knife mills. Wood flour can also be obtained from wood products operations such as sawmills, mill work or window and door manufacturers that produce sawdust as a byproduct. A study conducted by WSU has shown that sawmill residues, including bark, can be successfully utilized to extrude WPCs. It was observed that bark content as high as 25 percent could be included in the wood flour without significantly compromising the mechanical properties significantly; additionally, moisture resistance properties were shown to improve with inclusion of bark. It has also been shown that wood from insect-infested trees, even with significant levels of deterioration, could potentially be used for wood-plastic composite production (Yadama, et al. 2008).

Wood flours obtained from size reduction processes or as byproducts from wood manufacturing contain various sizes of particles. These wood particles are classified using vibrating, rotating or oscillating screens. The size of wood particles is often described by the mesh of the wire cloth sieves used to make them. For example, 20-mesh indicates wood flour that passes No.20 U.S. standard sieve (0.841mm per side square openings). Typically, wood particles between No. 10 to 80 U.S. standard sieve (2 and 0.18mm openings, respectively) are used. Companies exist that specialize in supplying wood fibers for WPCs. Prices vary but currently are in the range of \$0.05-\$0.15/lb.

An important aspect of wood particles for inclusion in WPCs is their aspect ratio – the length-to-diameter ratio. Normally, this value will range from 1 to 5. Wood flour with a low aspect ratio is easier to process (readily metered and fed).

Higher aspect ratios can increase mechanical properties such as strength, elongation and impact energy, but high aspect ratio could decrease processability. The equipment used to break down and classify the wood particles will influence the aspect ratio.

Wood species:

The commonly used wood species for commercial WPC production are pine, maple and oak. As with many wood-based products, regional availability and cost are key factors in species selection.

WPCs have been manufactured in the lab using a wide variety of species, including osage orange, walnut, yellow poplar, hickory, Utah juniper, salt cedar and emerald ash borer-infested ash. Research indicates that species effects on the mechanical properties of WPCs are small; however, they can have a substantial influence on the processing attributes of the WPC. In practice, wood species has not been considered to be an important variable; any fiber source that is readily available and inexpensive is generally preferred.

Recent research indicates that the inclusion of wood species with distinctive properties can positively influence the characteristics of the resulting WPC. For example, WPCs made with eastern red cedar and cherry are more resistant to water absorption, swelling and rot than those made with other wood species (Kim et al. 2008).

In addition to various wood species, various other natural fibers have been included into fiber-plastic composites. Examples include bast fibers (flax, hemp, jute, kenaf, ra-

mie), rice hulls, leaf fibers (sisal, pineapple, abaca), seed fibers (cotton), fruit fibers (coconut husk or coir) and stalk fibers (straw of various kinds). Use of some of these fibers could add additional steps to processing due the presence of high silica content and cuticle wax (Rowell et al. 1997).

Moisture content:

Wood flour must be dry before it is used in WPC manufacturing. Moisture evaporates and increases gas pressure during the high-temperature compounding and forming process. In addition, moisture in wood can create voids in the final product and thus adversely affect mechanical properties. Moisture content levels of 2 to 8 percent (dry weight basis) are typical, but also vary based upon the manufacturing platform. Moisture is removed from the wood prior to composite formation via a variety of drying methods, including steam tubes and rotary drums driers. Moisture is also removed during the composite processing step, minimizing its negative influence and allowing for higher product output. Wood flour and even pre-compounded material can absorb moisture under ambient conditions.

Therefore, the control of moisture in wood flour and compounded material is very important in processing wood plastic composites.

Plastics

WPCs are made with thermoplastic polymers. These materials melt and flow at high temperatures and harden when cooled. To prevent excessive damage to the wood component, thermoplastics for WPCs have processing temperatures of less than 220 degrees C.

Common materials used include polypropylene, polystyrene, polyvinylchloride and polyethylene (low and high density). Recycled polymers are often used, but they must be relatively clean and homogeneous; polymers of different types don't mix well.

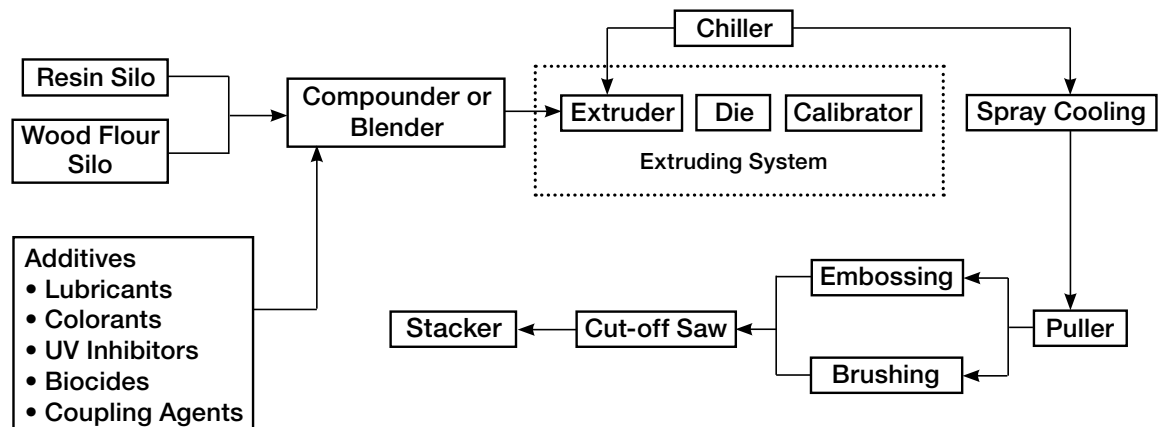
Additives

While the bulk of a WPC is wood flour and thermoplastic polymer, a variety of materials are added in relatively small quantities. These additives are included for a variety of reasons.

- Lubricants help the molten WPC mixture move through the processing equipment
- Coupling agents improve the wood and polymer interaction. Wood is naturally hydrophilic (attracts water), while the thermoplastic polymers are hydrophobic



A twin-screw extruder



The WPC manufacturing process, with extrusion forming

(repel water). This basic chemical incompatibility makes it very difficult to bond polymers to wood. The use of coupling agents can help to overcome this incompatibility.

- Fillers, such as talc, are used to reduce the cost of materials and to improve stiffness and durability.
- Biocides can be added to protect the wood component of WPCs from fungal and insect attack. Zinc borate is the most commonly used wood preservative added to WPCs. Fire-retardant chemicals reduce the tendency of the WPCs to burn. UV stabilizers help protect the plastics from degrading in the sun.
- Pigments are added to provide a desired color to the product. UV stabilizers can help to protect the color, but some fading and whitening will occur with most WPC's exposed to sunlight.

Manufacturing Technologies

Compounding:

Manufacturing of WPCs can be done using a variety of processes; however, the key to making any WPC is through efficient dispersion of the wood component into the thermoplastic matrix ('compounding'). Generally, this can be accomplished in twin-screw extruders or other melt-blending processes. Once the materials are sufficiently mixed, the composite can then be formed into the final shape using forming technologies such as extrusion or injection molding.

Forming:

Most WPCs are manufactured using profile extrusion, which creates long continuous elements, such as deck boards and window components. The wood-thermoplastic mixture (in pellet form) is conveyed into a hopper that feeds the extruder. As the material enters the first zone of the extruder, the heated screws and barrel melt or soften the thermoplastic. The molten material is then forced through a die to make a continuous profile of the desired shape. Molten WPC material is highly viscous, so the equipment needs to be powerful enough to force the material through the machinery and out of the die. As the material exits the extruder, it is cooled in a water spray chamber or bath to rapidly harden the thermoplastic matrix, embossed with a desired pattern, and cut to a final length. Extruders can have single screw or twin feed screws, which are counter- or co-rotating. These screws can be parallel, for mixing only, or conical, to increase pressure

in the die to aid in consolidation. Tandem extruders have one component for the compounding step and one for the shaping process.

While extrusion methods create lineal elements, injection molding produces three-dimensional parts and components. The unique shapes and profiles that can be created with injection molding provide the potential for diversifying from the current WPC markets. The injection molding process involves two steps. The first is to melt-blend or compound the wood-plastic mixture, and the second is to force the molten WPC into a mold under high pressure. The molten material fills the cavity in the mold and solidifies as it is cooled. Injection molding is used to manufacture a variety of parts, from small components to large objects. Injection molding is a common method of production and is especially useful for making irregularly shaped pieces.

Other types of molding processes include compression, vacuum



An injection molder

bag, resin transfer (RTM), reaction injection (RIM) and matched die molding. These manufacturing technologies each have the ability to keep the full length of the fiber and provide high strength composite, such as those used in automotive applications. The main disadvantages to these techniques are that they are batch processes, which require longer processing times and are more costly. All of these methods could have application to WPCs; however, only limited research has addressed their use.

Markets

The wood-plastic composites market share has been growing rapidly, especially for applications such as decking and railing. The main drivers for WPC acceptance are the perceived improved performance and appearance attributes (e.g., no checking) over existing products such as treated wood decking. Stricter regulations on the use of chemicals in building materials, such as the phasing out of CCA-treated lumber for residential decking and the desire for 'green' build-

ing materials (WPCs can use waste wood and recycled plastics) have also contributed to greater acceptance of WPCs by builders and homeowners.

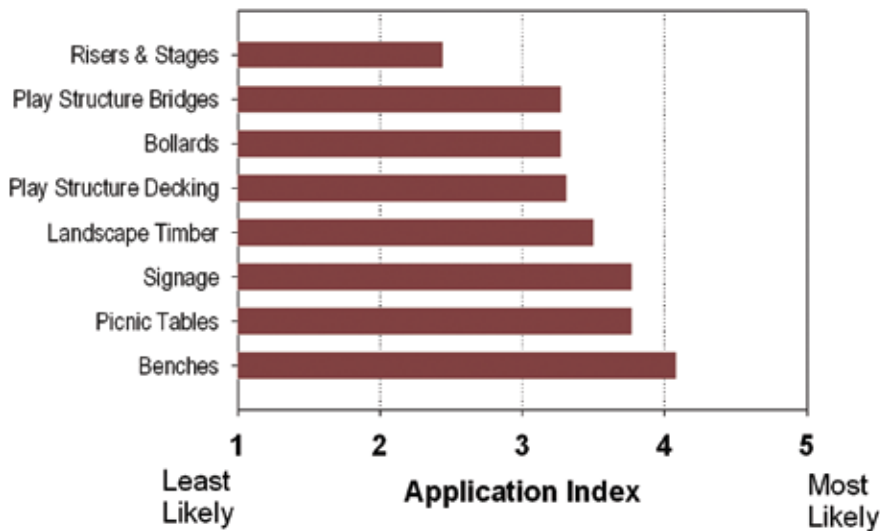
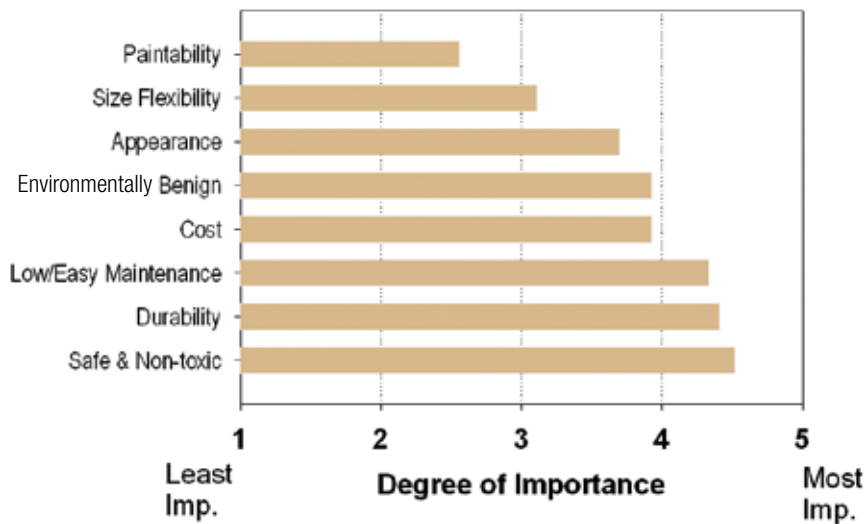
Two-thirds of the WPCs produced are decking and railing products, accounting for almost \$1 billion annually. Other important products are window and door frames. Additional potential applications for WPCs include siding, roofing, residential fencing, picnic tables, benches, landscape timber, patios, gazebos and walkways, and playground equipment.

Number of Extruders	WPC Manufacturing			Furnish (dry tons)		Green Wood (tons)	
	Operating Hours/Year	Production (nominal MBF)	Production (dry tons)	55% wood (2% MC)	34% HDPE	Wood (80% MC) dry basis no bark	Roundwood equivalents w/bark
1	2000	425	1250	701	425	1238	1386
	4000	851	2500	1403	850	2475	2772
5	2000	2127	6250	3506	2125	6188	6930
	4000	4255	12500	7013	4250	12375	13860
20	2000	8509	25000	14025	8500	24750	27720
	4000	17018	50000	28050	17000	49500	55440

Raw material requirements for a typical WPC plant (Brackley and Wolcott, 2008)

Capital Estimate	\$ millions per phase			
	Phase 1	Phase 2	Phase 3	Total
Equipment	5.87	7.12	11.43	24.42
Installation	3.95	1.68	3.80	9.43
Site Development	1.34	0.06	1.20	2.60
Buildings	4.18	0.00	3.19	7.37
Indirect Costs	2.07	1.20	2.65	5.92
Contingency	0.87	0.50	1.11	2.48
Total	18.28	10.56	23.38	52.22

Capital investment estimates for WPC plant – starting with 2 extruders in Phase 1, and expanding to 10 extruders in Phase 2 and 20 extruders in Phase 3 (Evergreen Engineering, 2005)



Potential applications and desired attributes of WPCs for playground equipment as indicated by Parks & Recreation officials (Yadama and Shook, 2004)

Summary

WPCs are new and rapidly evolving products. WPCs offer a number of advantages, including flexibility of production and the use of recycled material to create a recyclable product. Despite the wide array of possible finished forms, the manufacture of WPCs is relatively simple and uniform. WPCs have become well-established building materials, especially for residential decking, and are likely to be used for a wider array of applications in the future.

For more information

<http://www.wpcinfo.org/>

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